

SUBJECT: Status of Crew Safety Impact of
Certain Saturn V Failures during
S-IC Flight
Case 330

FROM: J. A. Llewellyn

The Saturn V control system gains were increased and the gain change times were modified in March 1967 to improve stability margins and controllability. With those changes, the LV capability to continue flight after single engine and actuator failures was enhanced, and crew safety was improved.

1. Structural beef-up of tension critical LV joints, effective SA-502 and up.
2. New chi-freeze schedule with modified times for freezing and unfreezing pitch program commands after an engine failure, effective SA-501 and up.

With these changes, probability of crew loss with any one of the failures studied appeared acceptable ($<10 \times 10^{-6}$). However a number of failures, such as loss of inertial attitude and actuator hardover, result in probabilities of vehicle loss which are undesirably high ($\approx 3000 \times 10^{-6}$).

A new potential problem is being evaluated whereby any abort attempt during the high Q portion of flight could cause the LV to breakup very rapidly.

(NASA-CR-154837) STATUS OF CREW SAFETY
IMPACT OF CERTAIN SATURN 5 FAILURES DURING
S-1C FLIGHT (Bellcomm, Inc.) 7 p

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BELLCOMM, INC.

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MEMORANDUM FOR FILE

I. INTRODUCTION

The intent of this memorandum is to briefly report on the analyses which have been accomplished - and those currently underway - regarding the S-IC flight malfunctions which are critical to crew safety. It is also intended to clarify the area of guidance and control hardware/software changes which have been made and those which are still "under consideration." This memorandum is essentially a summary of information gathered in recent meetings between MSFC and Boeing personnel and the writer. Much of the information is also contained in a Boeing document.⁽¹⁾

II. REFERENCE CONFIGURATION

The flight control and guidance system used herein as a reference was established in March, 1967, when the dynamic and static gains were increased and the gain switch times were changed. The gain modifications made at that time provided significant bending mode gain margins, aerodynamic gain margins, and better controllability during the high-Q flight regime. These improvements significantly enhanced the capability of the launch vehicle to survive control and engine malfunctions. However, considering the most pessimistic wind conditions and times of flight, more improvement was required to ensure maximum mission reliability and crew safety. See figure 1 for risk factors associated with the various failure modes. Risks are quoted for the reference configuration and reference configuration plus structural beef-up and new chi-freeze schedule.

III. RECENT CHANGES

A. Structural Beef-Up

Structural beef-up is being implemented at tension-critical launch vehicle joints. These changes improve capability to withstand structural loads after malfunctions and consequently improve launch vehicle survivability. Additionally, the changes afford more warning time prior to breakup in malfunction cases where abort is necessary. The effectivity is SA-502 and up.

B. New Chi-Freeze Schedule

A new chi-freeze schedule has been designed for single engine failure conditions. The new time after an engine failure at which the pitch program attitude command is frozen and the new freeze duration will reduce loads and improve controllability after the failure. The new freeze schedule is effective on SA-501 and up.

IV. PRESENT STATUS OF SIGNIFICANT S-IC FLIGHT FAILURE MODES (See Figure 1)

A. Single Engine Out Near Launch Pad

Yaw biasing has been implemented to eliminate tower collision with maximum launch winds. However, failure of either engine nearest the tower during the first 5 to 6 seconds of flight results in a high probability of tower collision. The problem now is to determine adequate abort warning cues for this malfunction. A recent Bellcomm study⁽²⁾ of engine failure during the first several seconds of flight shows that the time required for the launch vehicle to clear the tower may be as long as 30 seconds due to the marginally positive vertical acceleration.

Currently Boeing is engaged in a study of all near-pad failures and aborts, and will address the problem of selecting the proper abort cues for all such failure cases.

B. Single Engine Out During the First 40 Seconds of Flight

During the first 40 seconds of flight a single engine out could cause subsequent structural breakup or loss of attitude control. This is due to the large angles of attack developed in the off-nominal trajectory which results from the reduced thrust. The reduced thrust also reduces the effective control system gains. The two changes mentioned above, structural beef-up and new chi-freeze schedule, have essentially eliminated this failure mode from the crew safety "concern" list.

C. Single Engine Out During High-Q Flight

Prior to the structural beef-up change, loss of certain engines (relative to wind direction) during the high-Q portion of flight could cause a sudden (.6 sec after failure) structural breakup due to the dynamic transients. This failure possibility has been eliminated by incorporation of the structural beef-up change and modified chi-freeze schedule. However, loss of other engines (relative to the wind) during high-Q flight can still result in loss of control which causes eventual launch vehicle breakup. The two changes previously mentioned have reduced the

probability of vehicle loss under this failure condition to less than 100×10^{-6} and have increased crew warning time.

D. Actuator-to-Null

Actuator-to-null failures during any S-IC flight regime presents no problem to crew safety since the flight control gain changes enable the remaining actuator to effect satisfactory control authority.

E. Other Control System Failures

There are four significant control system failures which have not been materially affected by the changes implemented to date; they are:

- a. Actuator hardover
- b. Loss of inertial attitude
- c. Loss of attitude error signal
- d. Saturated control system.

Probability of crew loss due to these malfunctions is low due to early warning availability; however, probability of vehicle loss is relatively high based on current component reliability numbers. (See Figure 1.)

V DISCUSSION

Boeing is continuing their malfunction and abort studies both to eliminate the need for abort and to enhance abort reliability when abort is necessary; a conflicting requirement is to tailor abort limits to minimize the probability of a false abort. As of this date they have made the following two preliminary recommendations to MSFC which will require "in-depth" studies before they can be implemented:


- a. provide a spacecraft display of hardover actuator conditions (to allow early abort warning) and
- b. provide a capability for switchover to either the Spacecraft Guidance System or to manual control in the event of LV platform failures (to allow flight continuation).

The feasibility of these changes and their overall contribution to mission reliability and crew safety has yet to be established.

As of this writing a problem of significant potential magnitude is being evaluated by MSFC personnel. This is a newly discovered condition whereby the launch vehicle may breakup almost immediately following complete engine shutdown during the high-Q portion of flight. Complete engine shutdown is required

for positive separation between the spacecraft and the launch vehicle. If this unabortability problem materializes, it must be alleviated by some means (and there are a number of schemes being studied at this time) or serious steps must be taken to minimize the probability of abort during the high-Q period. Since Figure 1 did not reflect this potential problem, it shows a high probability of successful abort in that crew loss probabilities are only a small portion of the associated vehicle loss probabilities. Now if most aborts during high-Q are unsuccessful, these numbers will more nearly equal each other; that is, crew loss will approach vehicle loss. Note in particular the high failure rate of the inertial attitude system.

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J. A. LlewellynAttachment
Chart

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REFERENCES

1. D5-15705-3, Saturn V/Apollo Requirements for S-IC Emergency Detection System, SA-503, 6/1/67, Boeing Company
2. Jellinek, J., Saturn V-501 Engine-Out at Liftoff, Case 330, (DRAFT), July 24, 1967

MALFUNCTION	BASELINE (MARCH 1967 CONFIGURATION)		BASELINE, WITH STRUCTURAL BEEF-UP AND NEW CHI-FREEZE ADDED	
	PROBABILITY OF VEHICLE LOSS	PROBABILITY OF CREW LOSS**	PROBABILITY OF VEHICLE LOSS	PROBABILITY OF CREW LOSS**
ENGINE-OUT	311×10^{-6}	233×10^{-6}	81×10^{-6}	$<10 \times 10^{-6}$
ACTUATOR HARDOVER	1450×10^{-6}	$<10 \times 10^{-6}$	870×10^{-6}	$<10 \times 10^{-6}$
LOSS OF INERTIAL ATTITUDE	2129×10^{-6}	$<10 \times 10^{-6}$	NOT AFFECTED BY CHANGES	
LOSS OF ATTITUDE ERROR SIGNAL	42×10^{-6}	$<10 \times 10^{-6}$		
SATURATED CONTROL SIGNAL	99×10^{-6}	$<10 \times 10^{-6}$		
ACTUATOR TO NULL	$<10 \times 10^{-6}$	$<10 \times 10^{-6}$		

**CREW LOSS IS DEFINED AS FAILURE TO ATTAIN 1.0 SECOND WARNING TIME.

FIGURE 1: CREW SAFETY AND VEHICLE LOSS RISK FACTORS DURING S-IC FLIGHT

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